Chief Reader Report on Student Responses:

2025 AP® Biology Free-Response Questions

• Number of Students Scored	288,132		
• Number of Readers	1,424		
• Score Distribution	Exam Score	N	%At
	5	54,306	18.8
	4	69,446	24.1
	3	78,923	27.4
	2	60,673	21.1
	1	24,784	8.6
• Global Mean	3.24		

The following comments on the 2025 free-response questions for AP® Biology were written by the Chief Reader, Jay Mager, Ohio Northern University, Ada, Ohio; with substantial assistance from the Operational Exam Leader, Amy Doling, Simpson College, Indianola, Iowa; and Question Leaders, Cyndie Beale, West Valley High School, Fairbanks, Alaska; Rob Benedetto, Central Catholic High School, Lawrence, Massachusetts; Monika Biro, Aurora High School, Aurora, Ohio; Deborah Jones, Oxford High School, Oxford, Mississippi; Jeff Regier, Thompson Valley High School, Loveland, Colorado; and Michelle Solensky, University of Jamestown, Jamestown, North Dakota. The comments provide an overview of each free-response question and outline how students performed on the question, including typical student errors. General comments regarding the skills and content with which students frequently have the most difficulty are included. Some suggestions for improving student preparation in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question 1

Task: Interpreting and Evaluating Experimental Results
Topic: ER Translocation

	Max Points:	Mean Score:
Point A1	1.0	0.64
Point B1	1.0	0.79
Point B2	1.0	0.16
Point B3	1.0	0.83
Point C1	1.0	0.76
Point C2	1.0	0.89
Point C3	1.0	0.49
Point D1	1.0	0.14
Point D2	1.0	0.02

Overall Mean Score: 4.74

What were the responses to this question expected to demonstrate?

The stimulus of Question 1 explained that proteins that are secreted from a cell must be transported to the endoplasmic reticulum (ER) and that this transport can occur during or after translation. It describes a protein that is involved in each of these types of transport and explains the creation of small interfering RNAs (siRNAs) that reduce the expression of either the SR protein, which is necessary for transport during translation, or the Sec62 protein, which is necessary for transport after translation. Figure 1 shows the effect on Sec62 and SR protein production of each of the siRNAs, relative to a control siRNA. Figure 2 shows the amount of transport of three different proteins in cells that were treated with each type of siRNA.

In part A responses were expected to describe the function of ribosomes.

Part B referred students to Figure 1. In part B (i) and B (ii) responses were expected to demonstrate an understanding of experimental design (Skill 3.C). In part B (i) responses were expected to identify the dependent variable (Skill 3.C). In part B (ii) responses were expected to justify the control of measuring both proteins when treated with an siRNA that was created to interfere with only one of the proteins (Skill 3.C). In part B (iii) responses were expected to describe the effect of a specific treatment on the production of one of the proteins (Skill 4.B).

Parts C (i) and C (ii) referred students to Figure 2. In part C (i) responses were expected to identify the independent variable (Skill 3.C). In part C (ii) responses were expected to identify the protein(s) that showed an increase in transport in response to the Sec62 siRNA treatment (Skill 4.B). Part C (iii) assessed whether students could convert a difference in nucleotides to a difference in the number of amino acids encoded by those nucleotides; responses were expected to calculate that difference from the data provided (Skill 5.A; LO IST-1.O).

Part D (i) referred students to Figure 2 and described the claim that "protein 1 is the only tested protein that is transported to the ER following its complete translation in the cytosol." Responses were expected to support this claim by explaining that only protein 1 had reduced transport when cells were treated with Sec62 siRNA (Skill 6.B). Part D (ii) assessed whether students could use their understanding of factors that affect the transport of proteins across membranes to justify a claim that "amino acids close to the protein's amino terminus determine how likely the protein is to pass through the protein channel within the ER membrane." Responses were expected to explain that entry into the channel would be more likely if the channel and amino acids (at the amino terminus) had similar polarity or opposite charges (Skill 6.B; LO ENE-2.G).

How well did the responses address the course content related to this question? How well did the responses integrate the skill(s) required on this question?

Describing the function of subcellular components (Skill 1.A):

- A moderate number of responses correctly described protein synthesis as the function of ribosomes (part A; LO SYI-1.D). Some responses incorrectly focused on the role of ribosomes in protein transport rather than protein synthesis, and some responses described an incorrect function, such as transcription.

Identifying experimental procedures that are aligned to the question (Skill 3.C):

- Many responses correctly identified the dependent (part B (i)) and independent (part C (i)) variables using the figures provided.
- Few responses provided appropriate justification for an experimental control (part B (ii)). Many responses included vague references to a control as a "baseline" or an indicator of "what was normal," but few were able to explain that the researchers measured both proteins after treating cells with one kind of siRNA to determine whether that specific siRNA reduced production of the target protein but not the other protein.

Describing data from a table or graph (Skill 4.B):

- Most responses correctly described data from a graph. Most correctly described that SR production increased in cells treated with Sec62 siRNA (part B (iii)) and that proteins 2 and 3 had increased transport in the group treated with Sec62 siRNA.

Performing mathematical calculations (Skill 5.A; LO IST-1.O):

- A moderate number of responses used the biological concept that a 3-nucleotide codon directs the addition of 1 amino acid to translate a difference in nucleotides to a difference in amino acids between two proteins (part C (iii)). Some responses calculated the difference in nucleotides but either divided by 2 instead of 3 or did not divide the difference by 3 (to determine the number of codons/amino acids from the number of nucleotides) and instead reported the difference in nucleotides as the answer.

Supporting a claim with evidence from biological principles, concepts, processes, and/or data (Skill 6.B):

- Few responses provided an explanation that fully supported the claim in part D (i) that "protein 1 is the only tested protein that is transported to the ER following its complete translation in the cytosol." Some responses correctly described the pattern of reduced transport of protein 1 in cells treated with Sec62 siRNA but did complete their support for this claim by specifying that this pattern was only observed for protein 1 or that it was not observed for proteins 2 or 3. Some responses described other patterns within the graph that, although accurate, did not support this claim (e.g., that transport of protein 1 was lower in cells treated with Sec62 siRNA than in cells treated with SR siRNA).

- Very few responses provided an explanation that fully justified the claim in part D (ii) that “amino acids close to the protein’s amino terminus determine how likely the protein is to pass through the protein channel within the ER membrane” (LO ENE-2.G). Some responses correctly described the polarity of the cell membrane and how such polarity might affect protein transport; however, they did not connect this to the ability of a protein to pass through the channel. Some responses described features of an entire protein, such as size or folding, rather than the properties of the amino acids close to the protein’s amino terminus.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part A • Misconception: Ribosomes make amino acids. • Knowledge Gap: The function of ribosomes is to synthesize proteins—transport is associated with that process but is not the function of a ribosome.	Part A • “The function of ribosomes is to synthesize proteins from mRNA strands and respective amino acid molecules.” • “Ribosomes are used in the synthesis of proteins by being the site in which RNA is translated.” • “The function of ribosomes is to make and transport proteins.”
Part B (ii) • Skills Gap: Justifying the purpose of a control in the context of a specific experiment, moving beyond phrases like “establish a baseline” or “to see what is normal” (Skill 3.C)	Part B (ii) • “They were included as controls to see if Sec62 siRNA reduced Sec62 protein amounts but not the amount of SR.” • “Including the control of measuring both Sec62 and SR protein amount in cells treated with Sec62 siRNA only allows researchers to determine if Sec62 siRNA affects SR as well as Sec62.”
Part C (iii) • Knowledge Gap: Recognizing that calculating the difference in amino acids when given the number of nucleotides requires the division by 3 to account for 3 nucleotides being translated to 1 amino acid	Part C (iii) • “Protein 2 has 87 more amino acids than protein 1.”

Part D (i) • Skills Gap: Interpreting complex graphs with more than one independent variable (e.g., clustered bar graph) (Skill 6.B)	Part D (i) • "Of all three proteins, protein 1 is the only one which experienced a decrease in the relative amount of protein transported to the ER when Sec62 siRNA was added to the cell. As Sec 62 is the ER membrane protein needed for proteins transported after translation, the negative effect of Sec62 siRNA on protein 1 suggests it is transported to the ER following translation." • "In the Figure 2 experiment, % protein transported to the ER decreased for Protein 1 when Sec62 siRNA was added. Because Sec62 protein is used to transport proteins completed in the cytosol into the ER, and protein 1 transport decreased when Sec62 siRNA interfered with Sec62, it is clear that Protein 1 must be translated completely in the cytosol before being transported into the ER by Sec62. Proteins 2 and 3 increased transport under Sec62 siRNA so they must use SR to enter the ER during translation."
Part D (ii) • Skills Gap: Applying biological concept to a novel scenario (amino terminus entering ER through a protein channel) (Skill 6.C). • Misconception: The amino terminus of a protein has a poly(A) tail. There seems to be some confusion about components of mRNA and proteins.	Part D (ii) • "Proteins that are transported across membranes should have the same polarity of the protein channel they are going through. Polar amino acids will more easily go through channels with polar insides." • "Amino acids close to the protein's amino terminus will have similar polarity to the protein channel and will pass through the channel easier than amino acids that differ from the terminus."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve student performance on the exam?

- Ask students to practice explaining the experimental design and the reason(s) for including each group represented on a graph with respect to the question and study design.
    - **TIP:** Practice with published data to develop skills in reading and interpreting graphs; there are good secondary sources (e.g., *New Scientist*) that students could use to find a study that interests them. These typically include links to the primary source that may have graphs that students can practice with to identify the dependent and independent variables, experimental and control groups, and the patterns illustrated.
    - **TIP:** When asking students to practice interpreting graphs, start by asking, "What do you see?" (experimental design components, such as dependent and independent variables). Then ask, "What does it mean?" This is a longer discussion that requires students to compare the results of different treatments, identify and explain controls, and interpret patterns. After the discussion, ask students to explain it in written form—articulating these explanations is an additional skill that goes beyond explaining them verbally.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

From AP Classroom:

- Topic questions and progress checks from Topics 2.1, 2.6, 4.6, and 6.4 for formative assessments
- AP Daily videos, Topics 2.1, 2.6, 4.6, and 6.4, as well as Faculty Lectures 4 and 6

From the AP Biology Online Teacher Community:

- Data resources outlined in the Online Resources Recommended by AP Teachers

Question 2

Task: Interpreting and Evaluating Experimental Results with Graphing
Topic: Mating Behavior in Moths

	Max Points:	Mean Score:
Point A1	1.0	0.50
Point B1	1.0	0.88
Point B2	1.0	0.66
Point B3	1.0	0.63
Point B4	1.0	0.72
Point C1	1.0	0.75
Point C2	1.0	0.47
Point D1	1.0	0.34
Point D2	1.0	0.21

Overall Mean Score: 5.17

What were the responses to this question expected to demonstrate?

Question 2 presented a table of data from an experiment designed to investigate details of part of the signaling pathway that enables male moths to respond to pheromones released by female moths. Specifically, the question investigates whether the binding of the extracellular signaling molecule 20E to its receptor, DopEcR, affects male moth behavior. In the experiment, scientists inhibited the expression of the DopEcR gene and determined the effect of that manipulation on two types of moth activity: general activity, defined as "movement in any direction," and oriented activity, defined as "movement toward an area of high pheromone concentration."

Part A expected responses to describe the polarity of the portion of the receptor that is inside the membrane. This prompt assessed student understanding of the biological concept of polarity (Skill 1.A; LO SYI-1.B).

In part B (i) responses were expected to construct a bar graph (Points B1, B2, and B3) representing the experimental data (Skill 4.A). Part B (ii) expected responses to use the provided data to determine the type of activity (Point B4) that was affected by inhibiting the expression of the DopEcR gene (Skill 4.B).

In part C (i) responses were expected to use the provided data to identify the treatment group in which the oriented activity was greater than 50% of the general activity (Skill 4.B). Part C (ii) referred students to a figure illustrating a simplified model of a G-protein signaling pathway; students were then provided information about a mutation in the gene encoding the G protein. Responses were expected to predict the effect of this mutation on the oriented activity in male moths exposed to the pheromone (Skill 6.E; IST-3.G).

Part D (i) presented information about changes in gene expression that occur as male moths reach sexual maturity, and the scientists' claim that "this increase in gene expression increases the likelihood of males finding females." Responses were expected to use evidence from the information provided to support the scientists' claim (Skill 6.B). In part D (ii) responses were expected to explain how an inhibitor of the DopEcR pathway might serve as an effective chemical to protect crops from moth damage (Skill 6.E).

How well did the responses address the course content related to this question? How well did the responses integrate the skill(s) required on this question?

Describing the properties of biological macromolecules:

- A moderate number of responses correctly described the polar properties of biomolecules (the polarity of the portion of a protein inside a membrane is nonpolar/hydrophobic) (Skill 1.A).

Constructing an appropriately labeled graph and describing/evaluating data in the graph:

- Most responses represented the data in a bar graph (Skill 4.A).
- Many responses corrected constructed a bar graph (Skill 4.A).
- Many responses correctly labeled the graph and accurately plotted the data points and error bars (Skill 4.A).
- Many responses correctly determined the effect of inhibiting expression of a key gene (the type of activity affected by inhibiting DopEcR gene expression) (Skill 4.B).

Making predictions based on disruptions of a biological process:

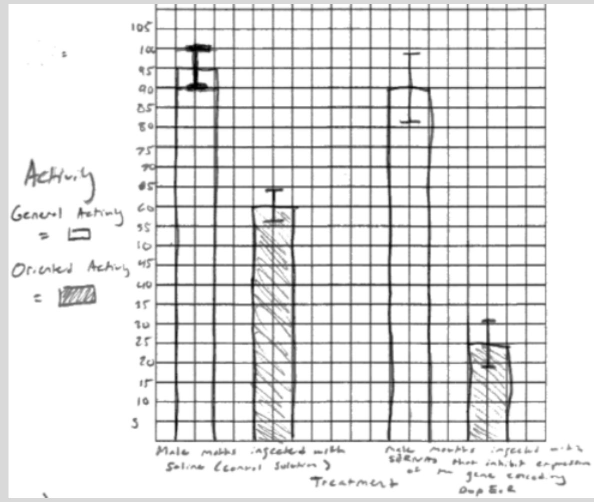
- Most responses correctly identified the treatment group specified (the one where oriented activity was greater than 50% of general activity), based on the data provided (Skill 4.B).
- A moderate number of responses correctly predicted the effect of a mutation on a biological process (a signaling pathway) (Skill 6.E).

Understanding a signaling pathway and explaining the impact of an inhibitor on the pathway:

- Some responses used evidence from the question to provide support for the scientists' claim (increased gene expression increases the likelihood of males finding females) (Skill 6.B).
- Fewer responses correctly explained the downstream effects of inhibiting a biological process (the DopEcR pathway) (Skill 6.E).

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Misconception: Molecules of opposite polarity attract each other	• "The portion of the receptor that is inside the membrane is nonpolar."
• Skills Gap: Inability to support a claim with evidence from biological principles, concepts, processes, and/or data (Skill 6.B)	• "As the expression of the DopEcR gene increases, oriented activity will increase, resulting in an increase of attracted mates."
• Skills Gap: Inability to to predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on a visual representation of a biological process (Skill 6.E)	• "This mutation prevents activation of the G-protein. This decreases oriented activity in male moths exposed to the pheromone."

• Skills Gap: Inability to label a graph and accurately plot data points and error bars (Skill 4.A); inability to utilize appropriate *y*-axis scaling	

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve student performance on the exam?

- Because graphs are found in multiple free-response questions in every exam, utilize graphs often, for increasingly complex data sets, and practice graph construction and interpretation.
- Give students practice in choosing when to use different types of graphs, how to appropriately label axes, how to scale such that all the data are contained in the graph, and how to use error bars to make conclusions.
- Practice articulating the steps in a biological process that lead to a result (For example: If there is a mutation or a change in a step in a cell signaling pathway, describe how this will change the response).

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

From AP Classroom:

- AP Daily videos, Topics 1.3, 2.3, and 4.3, as well as Faculty Lectures 1 and 4
- Topic questions and progress checks from Topics 1.3, 2.3, and 4.3 for formative assessments

From AP Biology Online Teacher Community Resources:

- Data resources outlined in the Online Resources Recommended by AP Teachers
- For graphing support and practice, the resources within the Quantitative Skills Guide

Question 3

Task: Scientific Investigation
Topic: Buffelgrass and Saguaro Cactus

	Max Points:	Mean Score:
Part A	1.0	0.32
Part B	1.0	0.60
Part C	1.0	0.55
Part D	1.0	0.25

Overall Mean Score: 1.72

What were the responses to this question expected to demonstrate?

Question 3 introduced buffelgrass, an invasive grass species in southwestern desert ecosystems, that is threatening the saguaro cactus, a keystone species in these ecosystems. The stimulus of the question described an experiment conducted to determine whether scientists could control the abundance of the buffelgrass population with native grasses. Several native grass species were identified that might reduce the abundance of buffelgrass when grown together. In this experiment, buffelgrass was grown in the presence of different native grasses in either drought or nondrought conditions, and the change in the height and dry weight of the buffelgrass were measured over time.

In part A responses were expected to describe how keystone species contribute to maintaining the diversity of an ecosystem as well as the relationship between ecosystem diversity and the ecosystem's resilience to changes in the environment (Skill 1.A; LO SY1-3.F).

In part B responses were expected to identify a control group to be included in the experiment testing the effect of native grass on the height and dry weight of buffelgrass (Skill 3.C).

In part C responses were expected to state the null hypothesis for this experiment (Skill 3.B).

In part D responses were expected to justify the claim that the abundance of invasive buffelgrass plants will increase in the ecosystem after a wildfire (Skill 6.B; LO SY1-2.A).

How well did the responses address the course content related to this question? How well did the responses integrate the skill(s) required on this question?

- In part A a moderate number of responses described the effect of removing a keystone species as the collapse of an ecosystem. Few responses connected their understanding of keystone species to the biodiversity in an ecosystem and the ecosystem's resulting resilience to change (Skill 1.A; LO SY1-3.F).

- In part B many responses identified the control for the experiment as buffelgrass grown alone without native species (Skill 3.C).

- In part C a moderate number of responses stated the null hypothesis for the experiment as there will be no change in the height and dry weight of the buffelgrass when grown in the presence of native grass species (Skill 3.B).

- In part D few responses justified the claim that the invasive buffelgrass will increase in abundance after a fire by using the information given regarding growth rates of buffelgrass and native grasses after a wildfire and then connecting that information to an understanding that these differences in growth rates will affect the abundance of the buffelgrass and native grasses (Skill 6C; LO SY1-2.A).

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part A Knowledge Gaps: • Inability to describe the significant role of a keystone species in an ecosystem: Many responses did not describe the removal of a keystone species as affecting the biodiversity and resilience of an ecosystem but instead described the effect as a negative outcome on a single food chain. • Inability to properly refer to the different levels of organization within an ecosystem (population/community/ecosystem and food chains/trophic levels/food webs) and describe how their interactions may affect biodiversity within the whole ecosystem: Many responses used the terms population, species, and community interchangeably and focused on the effect of the loss of a keystone species on a single food chain.	Part A • "Removing a keystone species would lead to a severe decrease in biodiversity and resilience in the ecosystem and could cause it to collapse." • "Removing a keystone species from an ecosystem will have a negative effect on the ecosystem. The removal of a keystone species will result in a top-down effect in which many species and populations will decrease. Overall, this reduces the biodiversity in an ecosystem, making it less resilient." • "Removing a keystone species will impact all trophic levels of an ecosystem. First, removing that species could result in an overabundance of species that is consumed by the keystone species, leading to the depletion of the species preyed upon by the keystone species' prey. It will have impacts on trophic levels above and below that cause an imbalance that cannot be resolved. It will cause a severe reduction of biodiversity and make the ecosystem more at risk."
Part B • Misconception: A control group is equivalent to the controlled variables in an experiment. Many responses did not identify a control group as the group not exposed to the independent variable. Instead, these responses identified a control group as the groups with the same exposure to water, light, temperature, and other factors that are to be kept constant in the experiment (Skill 3.C).	Part B • "A control group the scientist should include is simply a wildtype buffelgrass that is grown without the native species in both conditions (nondrought and drought)." • "Grow buffelgrass alone without any of those native grass species and measure its height and dry weight."

Part C Skills Gaps: • A null hypothesis means there will always be a decrease, negative effect, or a decline within a study. • A null hypothesis is mistaken for an experimental hypothesis. Many responses did not state a null hypothesis that the independent variable has no effect on the dependent variable in the experiment. Instead, responses provided a hypothesis stating that the buffelgrass would survive in the presence of native grasses or that the native grasses would reduce the abundance of buffelgrass (Skill 3.B).	Part C • "The presence of native grass species will have no effect on the height and dry weight of the buffelgrass" • "There is no change in height or dry weight of the buffelgrass when in the presence of a native species, and any change is due to chance." • "The growth of buffelgrass is unaffected by the presence of a native grass species." • "The presence of native species has no significant effect on buffelgrass growth."
Part D • Skills Gap/Knowledge Gap: Inability to justify a claim using information given AND knowledge of biological principles, concepts, processes, and data (Skill 6.C). Many responses did not apply knowledge of how invasive species affect ecosystem dynamics (LO SYI-2.1, LO SYI – 2.A.1). Instead, most responses restated the stimulus and did not use knowledge of biological concepts to explain *why* the expected change will occur.	Part D • "This is true because buffelgrass will have no competition as it grows exponentially after a fire while the native species are slower to come back." • "Wildfires will increase the abundance of buffelgrass plants due to less competition from native species. Because the growth of native grasses slows down after a wildfire, there will be more resources/nutrients and space available for the drought-tolerant buffelgrass. This allows the buffelgrass population to grow and the abundance of it to increase." • "The scientists' claim is justified by the fact that the fast rate of buffelgrass growth after a wildfire, compared to the slower growth rate of other native species, will allow the buffelgrass to outcompete with the other species by taking up the space and nutrients before the other plants get a chance to grow, leading to an increased abundance of buffelgrass."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve student performance on the exam?

- Provide opportunities for students to model complex interactions between multiple species in an ecosystem, including keystone species. Build models by layering food chains on top of food chains to build food webs, communities, and ultimately ecosystems. Then let students explore disruptions to the ecosystem, make predictions or claims, and use their models to justify their claims.
    - **TIP:** Allow students to collaborate to build these models and explain their reasoning as they make and justify claims, both verbally and in writing, correctly using terminology (e.g., population, community, ecosystem, keystone population) from the course.
    - **TIP:** Provide students with multiple scenarios to apply their understanding of these ecological concepts to new contexts.
- Challenge students to design experiments, clearly stating both experimental and null hypotheses, identifying independent and dependent variables, and describing the factors that must be held constant.
    - **TIP:** In each unit, ask a scientific question and challenge students to design an experiment to answer the question. Allow students to collaborate to design and conduct experiments.
- Provide multiple opportunities for students to analyze their experiments through Claim-Evidence-Reasoning and to present their CER to their peers.
    - **TIP:** Frequent practice helps students understand the differences between evidence and reasoning and justification. Responses to “provide evidence to support the claim” and “justify the claim” are often the same. Teach students that evidence supports the *what* of the claim (i.e., what change is observed). Justification asks students to apply their understanding of biological concepts to explain *why* the claim is happening.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

From AP Classroom:

- Topic questions and progress checks from Topics 8.6 and 8.7 for formative assessments
- AP Daily videos, Topics 8.6 and 8.7, as well as Faculty Lecture 8

From the AP Biology Online Teacher Community:

- Data resources outlined in the Online Resources Recommended by AP Teachers

Question 4

Task: Conceptual Analysis
Topic: Isthmus of Panama

	Max Points:	Mean Score:
Part A	1.0	0.12
Part B	1.0	0.27
Part C	1.0	0.71
Part D	1.0	0.61

Overall Mean Score: 1.72

What were the responses to this question expected to demonstrate?

Question 4 introduced a major geologic event, the formation of the Isthmus of Panama, which occurred millions of years ago and affected the evolution of both marine species and species living in South America. The stimulus of the question explained that the formation of the Isthmus separated the Caribbean Sea and the Pacific Ocean and created different environmental conditions for the species living there. These environmental changes initiated the speciation processes of marine organisms and altered the ecological interactions of land species.

Responses in part A were expected to describe the genetic evidence that evolution is occurring in a population (Skill 1.A; LO EVO-1.L).

Responses in part B were expected to explain how the isolation of marine species by the formation of a land barrier can lead to divergent evolution of those species (Skill 1.B; LO EVO-3.E).

Responses in part C were expected to predict the effect the formation of the Isthmus had on resource availability for South American species (Skill 3.B; LO ENE-4.B).

Responses in part D were expected to justify the predicted effect with respect to resource availability for South American species (Skill 6.C; LO ENE-4.B).

How well did the responses address the course content related to this question? How well did the responses integrate the skill(s) required on this question?

- Few responses correctly described the genetic evidence that evolution is occurring in a population (Skill 1.A; LO EVO-1.L).
- Some responses clearly and accurately explained how geographic isolation of marine species can lead to divergent evolution of those species (Skill 1.B; LO EVO-3.E).
- Many responses correctly predicted how the formation of the Isthmus of Panama would affect the resource availability for South American land animal species (Skill 6.E; LO ENE-4.B).
- Many responses correctly justified the reason for the decreased resource availability for the South American species of land animals (Skill 6.C; LO ENE-4.B).

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Misconceptions: • The lack of the conditions of the Hardy–Weinberg equilibrium alone is sufficient as genetic evidence of evolution. • Adaptation is an umbrella term that is commonly used in place of any other term in evolution and any evolutionary process, including speciation. • Differences in DNA sequences in organisms equals evolution. • Changes in the environment cause new traits to develop. • Expanding the range/land mass that populations can occupy automatically increases resources, disregarding the species that are already living there.	• “Genetic evidence for evolution includes changes in allele frequency in the population over time.” • “The isolation of marine species by the land barrier results in reproductive isolation, in which groups of the separated populations are no longer able to interbreed and produce fertile, viable offspring.” • “Genetic evidence for evolution includes changes in allele frequencies in a population over time. This can be seen through DNA analysis showing genetic differences between populations or the appearance of new mutations.” • “Geographic isolation of marine species would prevent individuals on each side of the barrier from mating. Additionally, the barrier would create two different environments in which different traits would be favored and passed down. This would lead to different changes in allele frequencies on each side of the barrier.” • “North American species migrated to South America and competed for similar resources like food with the South American species.”
Knowledge Gaps: • Overall, the language of the responses was inaccurate and ambiguous. • “Phenotype” and “gene frequency” are not interchangeable terms.	• “The formation of the isthmus decreased resource availability for South American species.” • “Evolution is occurring in a population if allele frequencies are changing between generations. This means that ... genotypes (and as a result, expressed phenotypes) are becoming different.”

Skills Gaps: • Many responses demonstrated the inability to concisely describe biological concepts and processes (Skills 1.A and 1.B). • Many responses demonstrated the inability to chose a term to demonstrate directionality of changes in ecosystems (Skill 6.E). • Many responses demonstrated the inability to justify a claim (about how the South American species will be affected by the migration of North American land animal species) based on the provided evidence (Skill 6.C).	• "The genetic evidence that evolution is occurring in a population includes a change in allele frequencies." • "Resource availability for South American species will decrease." • "As the North American species are occupying similar niches as the South American ones, they will be competing for resources."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve student performance on the exam?

- Provide opportunities in class for students to express their knowledge and understanding verbally and in writing to reinforce fundamental questions in evolution (e.g., natural selection).
    - **TIP:** Allow students to work in groups so they can solve and analyze problems together.
    - **TIP:** Give students regular formative checks so that they can score responses for each other. During the scoring process, allow them to ask questions and clarifications to understand how to express their thoughts more clearly.
    - **TIP:** Use dry-erase boards (or something similar) during review, so you can walk around and check students' thinking and writing as they work out the answers.
- Provide sample questions with various task verbs throughout the year.
    - **TIP:** Model how to use the task verbs during review and assessments.
    - **TIP:** At the beginning of the year, provide students with the definitions of the task verbs from the *AP Biology Course and Exam Description.*
- Use case studies, primary research, and graphs to illustrate various specific examples of biological concepts and processes in ecology and evolution.
- Use case studies and various specific examples to predict and justify the consequences of changes and disruptions in populations as a result of abiotic events (e.g., creation of geological barriers, introduction into new environments) and biotic events (e.g., competition).
- Apply the concept of evolution in different contexts and scenarios.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

From AP Classroom:

- Topic questions and progress checks from Topics 7.1, 7.3, 7.5, and 8.7 for formative assessments
- AP Daily videos, Topics 7.1, 7.3, 7.5, and 8.7, as well as Faculty Lectures 7 and 8

Question 5

Task: Analyze Model or Visual Representation of a Biological Concept or Process
Topic: Synthesis of Amino Acid

	Max Points:	Mean Score:
Part A	1.0	0.55
Part B	1.0	0.37
Part C	1.0	0.72
Part D	1.0	0.36

Overall Mean Score: 2.00

What were the responses to this question expected to demonstrate?

The stimulus of Question 5 provided a model of a multistep metabolic pathway transforming one amino acid, A, into another amino acid, B. The model displayed three enzymatic reactions and ended with amino acid B allosterically inhibiting the first enzyme (enzyme 1) of the pathway.

In part A the responses were expected to describe a characteristic of an enzyme's active site that allows it to catalyze specific reactions (Skill 1.A; LOs ENE-1.D and ENE-1.E).

In part B the responses were expected to explain how the binding of the first amino acid (A) to its enzyme (1) was regulated by the presence of another amino acid (B) (Skill 2.B; LO ENE-1.D and ENE-1.F).

In part C the responses were expected to identify the product of one of the enzymatically controlled reactions within the metabolic pathway (Skill 2.D; LO ENE-1.D).

In part D the responses were expected to explain how changes in environmental pH could affect one of the enzymes (3) within the metabolic pathway, altering the amount of product produced (amino acid B) by this reaction (Skill 2.C; LOs ENE-1.G and ENE-1.F).

How well did the responses address the course content related to this question? How well did the responses integrate the skill(s) required on this question?

Enzyme Characteristics:

- Many responses indicated that the shape or chemical characteristics of the enzyme's active site must be compatible with the substrate for specific chemical reactions to occur (Skill 1.A; EKs ENE-1.D.1 and ENE-1.D.2).
- Some responses focused on enzyme-substrate molecular interactions that resulted in the chemical reaction (Skill 1.A; EKs ENE-1.D.2. and ENE-1.E.1).
- Some responses incorrectly described components of enzyme-mediated reactions or indicated that enzymes change in these reactions.

Explanations of Enzymatic Feedback Loops Using a Model:

- Some responses explained that the interaction between one molecule and an enzyme (amino acid B and enzyme 1) prevented the interaction between the enzyme and its substrate (enzyme 1 and amino acid A) (Skill 2.B; LO ENE-1.F).

- Some responses explained that the interaction between one molecule and the enzyme (amino acid B and enzyme 1) was an allosteric inhibition feedback mechanism and that the inhibitor (amino acid B) altered the shape of the enzyme's active site, preventing any interaction with its substrate (amino acid A) (Skill 2.B; LO ENE-1.D, ENE-1.G).
- Some responses incorrectly interpreted the model and indicated that the presence of the inhibitor molecule (amino acid B) is an activator that enables the enzyme to function (allows enzyme 1 to interact with amino acid A).
- Many responses incorrectly explained that the model and interactions demonstrated enzyme regulation via competitive inhibition.

Identifying Elements of a Model:

- Most responses properly identified the product of the enzymatic reaction involving enzyme 2 (Skill 2.D; LO ENE-1.E).

Environmental Factors Affecting Enzymes and Metabolic Pathways:

- Some responses explained how pH could affect an enzyme's shape and functionality, resulting in its inability to interact with its substrate (intermediate Y) (Skill 2.C; EKs ENE-1.F and ENE-1.G).
- Many responses explained that enzymes denature in suboptimal conditions; however, they did not go far enough to explain why the final product (amino acid B) was not produced.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part A Misconceptions: • Enzymes and receptors perform the same functions. • Ligands and substrates are synonyms.	Part A • "active sites have a specific shape which allows specific amino acids to bind" • "substrates are compatible with certain enzymes"
Part B • Misconceptions: Confusion between competitve and noncompetitive inhibition. • Misconception: Allosteric and active sites are interchangeable or the same. • Misconception: Confusion between positive and negative feedback regulation. • Skills Gap: Identifying action elements of a metabolic pathway model (e.g., T-bars vs. arrows) (Skill 2.B).	Part B • "amino acid B is an inhibitor to enzyme 1 and prevents amino acid A from binding to the enzyme" • "amino acid B is an allosteric inhibitor that when attached to enzyme 1 changes the shape of the enzyme's active site so that amino acid A cannot attach to enzyme 1"

Part C • Skills Gap: Distinguising between elements and actions in a model (Skill 2.D)	Part C • “intermediate Y”
Part D • Skills Gap: Explaining what happens outside of the boundaries of the model once the model has been disrupted (Skill 2.C)	Part D • “lowering the pH can denature enzyme 3 which would make it impossible for intermediate Y to bind to the enzyme and synthesize amino acid B” • “a change in pH will change the shape of enzyme 3’s active site and…the substrate will no longer attach to the enzyme”

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve student performance on the exam?

- Assess student use of language and communication skills.
  - **TIP:** Have students write responses and then read responses aloud. Provide immediate feedback.
- Apply feedback principles across all scales (biomolecular to ecosystem).
  - **TIP:** Describe positive and negative feedback to students, and ask them to describe how systems across the curriculum self-regulate.
- Have students construct, interact, and manipulate models (do not just have them interpret existing models).
- Add disruptions to the models students construct.
  - **TIP:** Have students make and justify predictions when elements or actions of a model are altered.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

From AP Classroom:

- Topic questions and progress checks from Topics 3.1 and 3.2 for formative assessments
- AP Daily videos, Topics 3.1 and 3.2, as well as Faculty Lecture 3

Question 6

Task: Analyze Data
Topic: ALD and Meiosis

	Max Points:	**Mean Score:**
Part A	1.0	0.73
Part B	1.0	0.67
Part C	1.0	0.25
Part D	1.0	0.04

Overall Mean Score: 1.7

What were the responses to this question expected to demonstrate?

Question 6 analyzed data for the *ald* gene in fruit flies that encodes the ALD protein, which is associated with centromeres and protein filaments involved in separating homologous chromosomes in meiosis. Four mutations of the *ald* gene were generated, and scientists analyzed different *ald* genotypes in comparison to homozygous *WT/WT*. Students were asked to compare two data sets, one presenting the impact of the various genotypes on the percentage of cells with ALD-associated filaments, and one showing the amount of ALD protein produced.

Part A asked students to identify which fly genotype produced a specific percentage of cells with ALD-associated filaments (Skill 4.B).

Part B asked students to describe the difference between two specific genotypes in ALD protein production (Skill 4.B).

Part C asked students to use the two data sets to support a hypothesis that "gamete-forming metaphase cells can produce a normal amount of ALD-associated filaments even when they produce half as much ALD protein as the wild-type cells produce" (Skill 5.B).

Part D asked students to explain why two specific genotypes could produce the same amount of ALD protein but have different phenotypes (Skill 6.D; IST-2.E).

How well did the responses address the course content related to this question? How well did the responses integrate the skill(s) required on this question?

- Many responses correctly identified a specific data point (the genotype with an average percent of cells with ALD-associated filaments close to 12%) (Skill 4.B).
- Many responses correctly described the difference in ALD protein production between two genotypes (Skill 4.B).
- Some responses were able to use data from two different data sets (percent of metaphase cells with ALD-associated filaments and ALD protein amount) to support a hypothesis (Skill 5.D).
- Some responses were able to use the data to support the scientists' hypothesis that even with only half of the ALD protein production, there was no difference in the amount of ALD-associated filaments produced by metaphase cells (Skill 5.D).
- Few responses were able to use the data to fully explain why two genotypes (*WT/del* and *ald1/del*) could produce the same amount of protein but have different phenotypes (Skill 6.D; IST-2.E).

- Some responses incorrectly associated a mutation as resulting in a nonfunctional protein rather than having reduced function or failed to give a qualifier for how the protein product was different (IST-2.E).
- Many responses failed to connect the production of a protein (ALD protein) with the resulting phenotype (ALD-associated filaments) (IST-2.E.1).

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
Part B • Skills Gap: Even when told which data set to reference, the wrong data set was used to answer the question (Skill 4.B).	Part B • "Flies with the genotype *ald3/ald23* produce a small amount of ALD protein while flies with the genotype *ald23/del* produce absolutely none."
Part C • Misconception: There can be arithmetic differences in data that have no statistical significance.	Part C • "Figure 1A shows the wild type having a percent of metaphase cells with ALD-associated filaments around 60%, and the *WT/del* to be around 75%. Since the error bars of these two overlap, they are not significantly different."
Part C • Skills Gap: The ability to compare different data sets in multiple figures (Skill 4.B)	Part C • "We see in Figure 1B that *WT/WT* is double the thickness of *WT/del* ... indicating that *WT/del* ... produce about half as much ALD protein as the wild types produces. However in Figure 1A the *WT/del* still produce a normal amount of ALD-associated filaments showing that gamete-forming metaphase cells can produce a normal amount of ALD-associated filaments despite producing less ALD protein."
Part D • Misconception: A change in genotype/mutation results in a nonfunctional protein/phenotype (LO IST-2.E).	Part D • "Even though the proteins are being produced, they are not the same, the flies with the *ald1/del* genotype have a much less functional variant compared to those carrying *WT/del,* and so even if they produce the same amount of protein, the fly with the *ald/1/del* genotype is not having a normal amount of filament produced."

Part D • Misconception: Organisms with two different alleles only produce one protein if one of them is the wildtype (EK IST-2.E.1.a.i).	Part D • "Wild type (homozygous) is normal, reasoning that *WT/del* would function somewhat similarly to normal and produce half as much ALD protein."
Part D • Skills Gap: Inability to explain the relationship between experimental results and larger biological concepts, processes, or theories (Skill 6.D)	Part D • "Because the ALD protein made by *ald1/del* is less functional and efficient than the ALD protein made by *WT/del*. Less functional proteins are unable to do their job as well, which would result in less ALD-associated filaments."

Based on your experience at the AP® Reading with student responses, what advice would you offer teachers to help them improve student performance on the exam?

- Provide opportunities in class for students to analyze experimental data, particularly in experiments where the students cannot draw conclusions if they cannot correctly interpret the data in two or more sets.
  - **TIP:** Use information in one data set or figure to describe how it relates to another data set.
  - **TIP:** Use specific examples of gene mutations that produce proteins of reduced function or enhanced function rather than having no function.
  - **TIP:** Reinforce the central dogma and what gene products do. DNA contains genes, and a gene encodes a protein, which has a function and is evident as the phenotype.
  - **TIP:** At the cellular level, have students explain why an organism with cells that are heterozygous for a mutation may have a normal phenotype or may have an altered phenotype.
  - **TIP:** Have students practice determining whether data are statistically significant.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

From AP Classroom:

- Topic questions and progress checks from Topics 5.3, 5.4, 6.5, and 6.6 for formative assessments
- AP Daily videos, Topics 5.3, 5.4, 6.5, and 6.6, as well as Faculty Lectures 5 and 6

From AP Biology Online Teacher Community Resources:

- Data resources outlined in the Online Resources Recommended by AP Teachers
- For graphing support and practice, the resources within the Quantitative Skills Guide